Reconstruction of pile-up events using a one-dimensional convolutional autoencoder for the NEDA detector array

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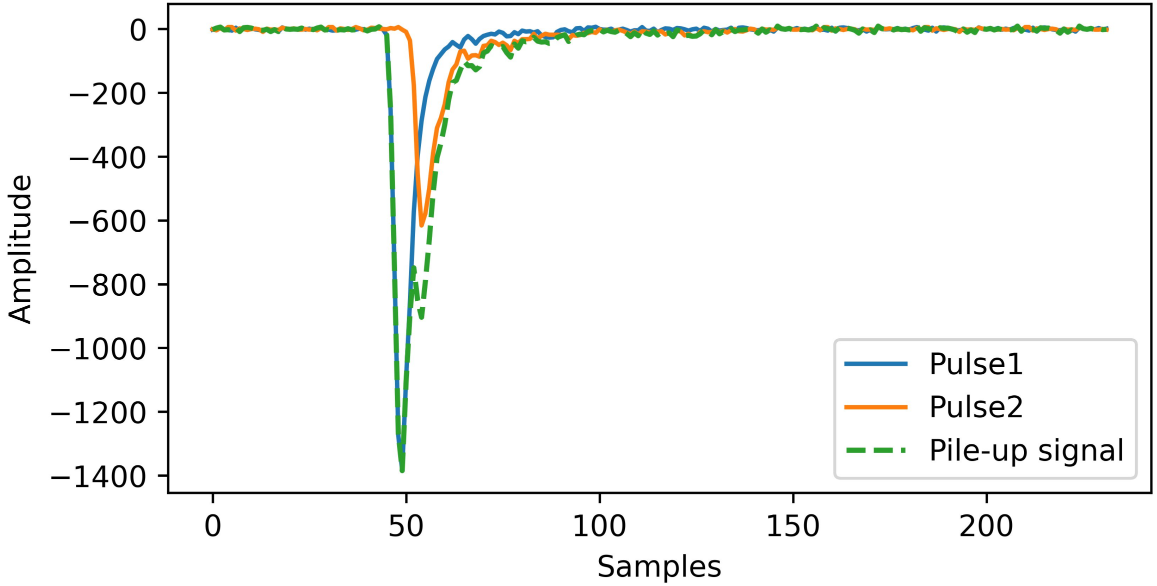
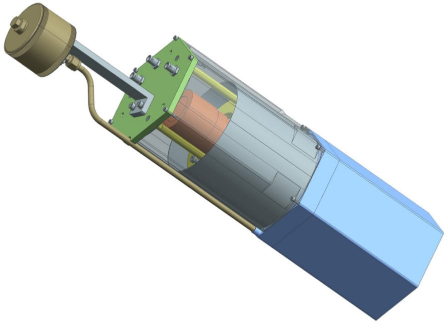
1. Introduction to pile-up concept

- Pulse pile-up is a common problem in nuclear reaction and spectroscopy experiments with high counting rates.
- **The pulse pile-up effect happens when pulses arrive close in time** so that both pulses are totally or partially overlapping.
- **Typically these events are discarded** during data acquisition since they cannot be analysed independently.

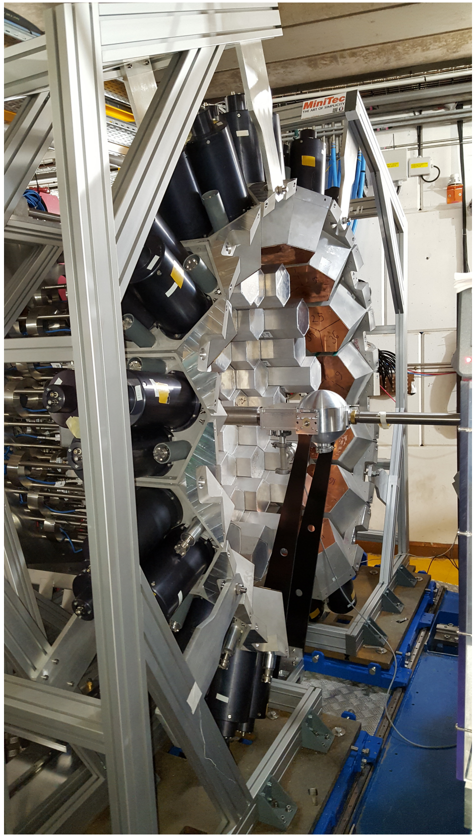


2. Pile-up in NEDA detector

- NEDA detector array is a neutron detector responsible for determining the reaction channel by measuring the number of neutrons emitted from the compound nuclei when working with a gamma-ray spectrometer.
- The NEDA array is based on individual hexagonal cells filled with **liquid organic scintillator.**
- Detector exhibits **sensitivity to neutrons, and gamma-ray.**
- A digitiser is responsible for digitising signals, allowing them to be analysed offline



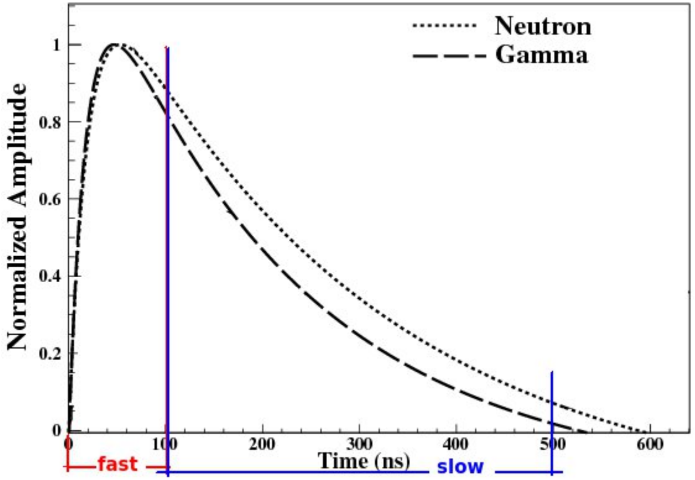
NEDA cell



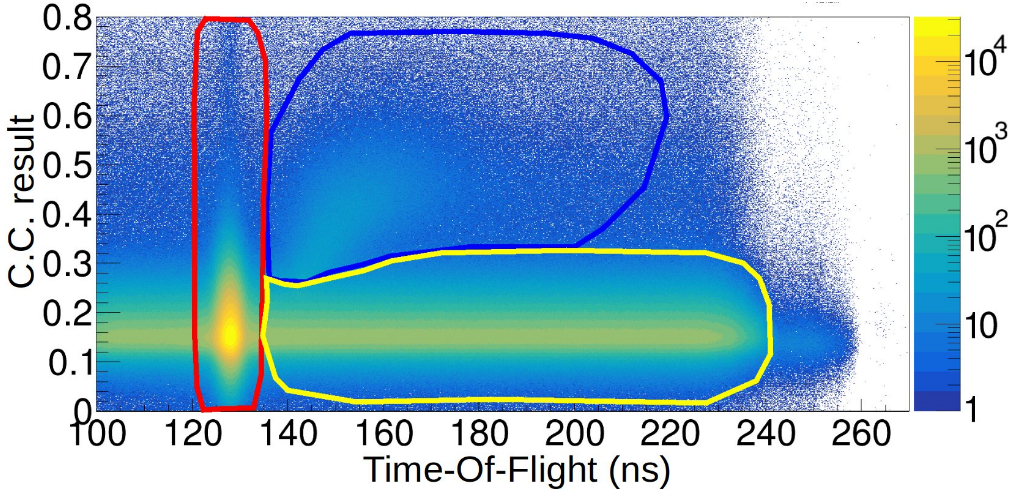
Example of NEDA instaled with other detectos

2. Pile-up in NEDA detector

- The signals generated by gammas and neutrons are similar, so **Neutron-Gama Discrimination** (NGD) methods need to be applied.
- In NEDA the NGD is based on: **Charge Comparison and Time-Of-Flight**
- When pile-up signals are generated NGD cannot be performed correctly and the signals are discarded.



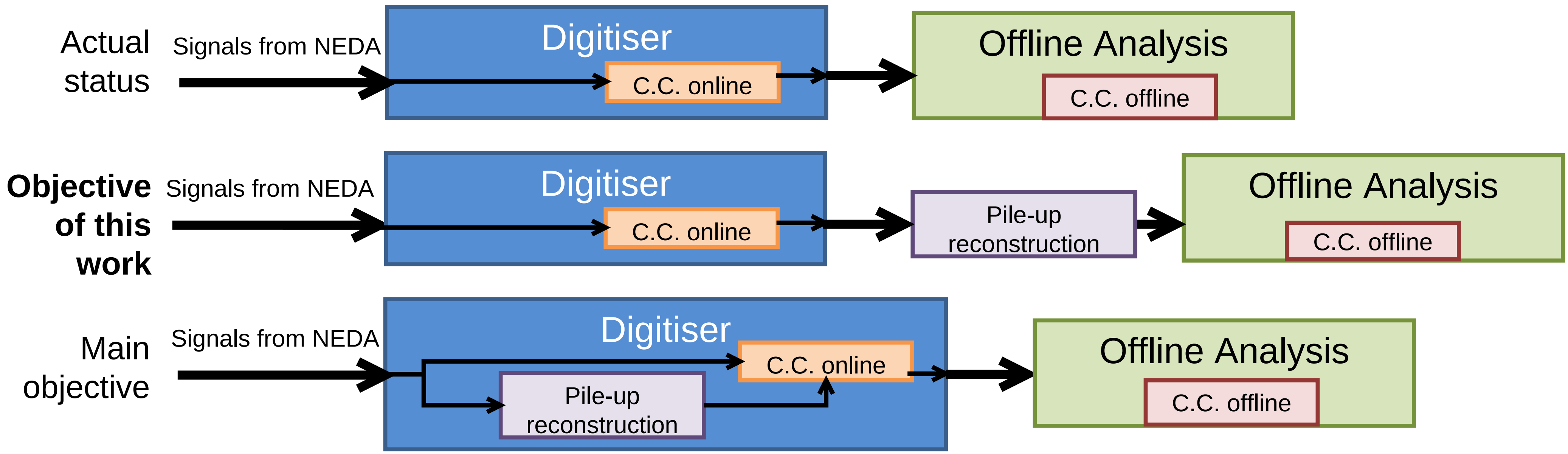
Simple example of the difference between normalized neutron and gamma signals



Particle discrimination: Neutron (blue), prompt gammas (red) and uncorrelated gammas (yellow)

2. Pile-up in NEDA detector

- The main objective of this work is to develop a method to **separate and reconstruct the pulse shape of the two pulses** from which the pile-up signal is formed.
- This method must be able **to be integrated into online digital processing and without modifying** the rest of the **acquisition and analysis chain.**
- **Previous step with offline pile-up reconstruction** to check the feasibility of the method.



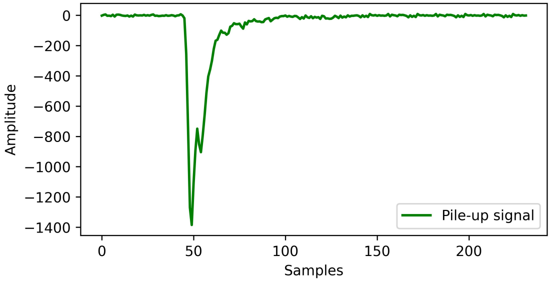
2. Pile-up in NEDA detector

- Types of combinations on which the method has focused are:
  - **gamma - neutron**
  - **neutron - gamma**

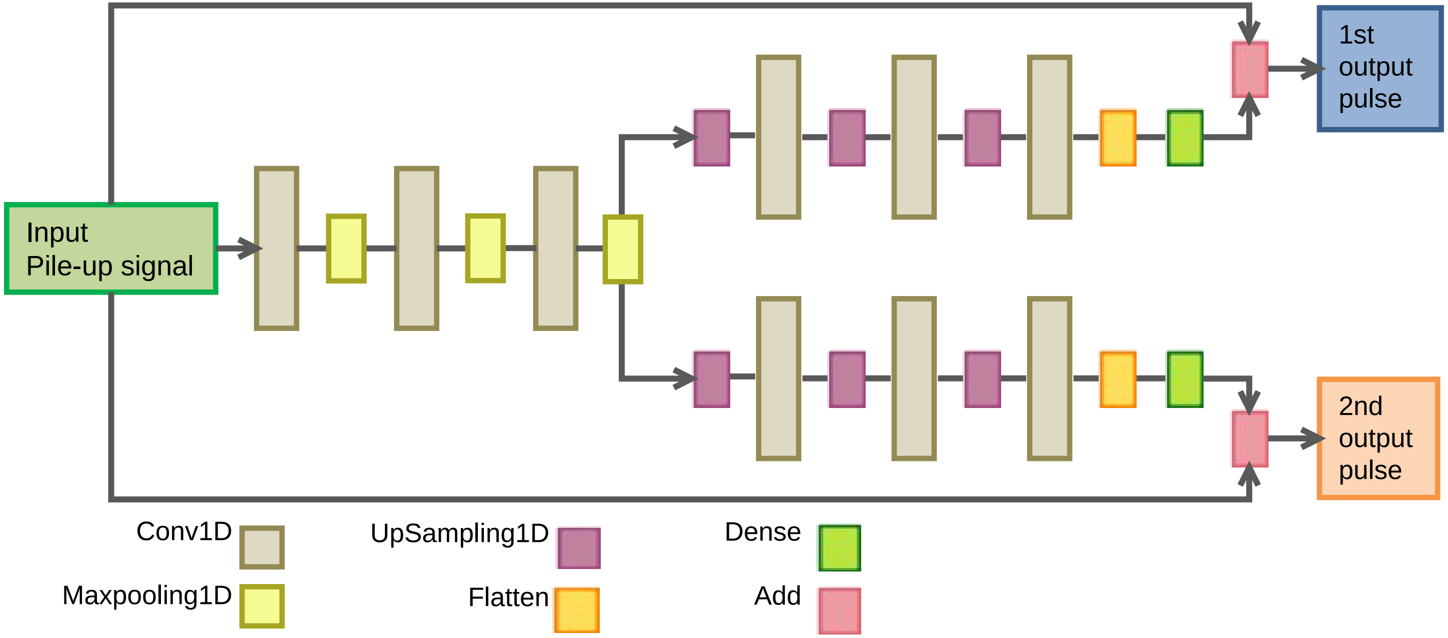
- Constraints:
  - **Integrable** in the acquisition chain
  - Able to separate and reconstruct **regardless of the distance between pulses**
  - Fast, to **integrate it in the future into online signal processing.**

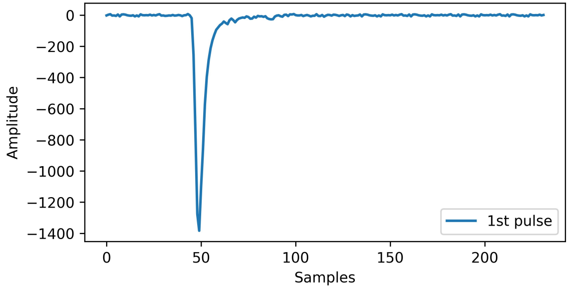
- This work proposes an ad-hoc machine learning method using a **1D-CAE architecture** to disentangle the two pulses composing each pile-up signal acquired with NEDA detectors.

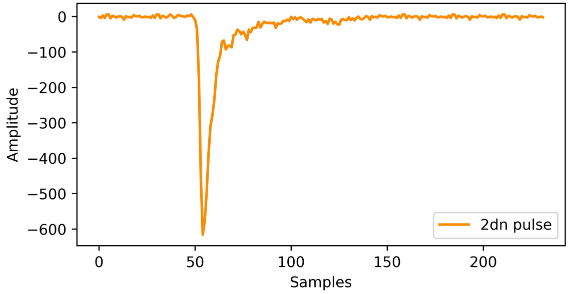
3. 1D-CAE architecture



- Architecture: Autoencoder based on 1D-CNN.
- Input signal with two pile-up pulses
- Two outputs, one for each pulse.

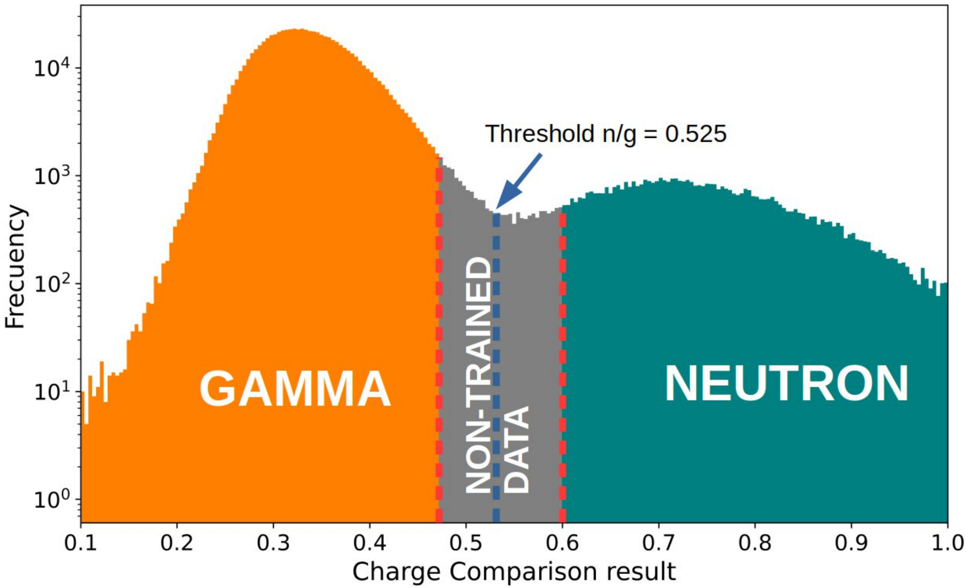






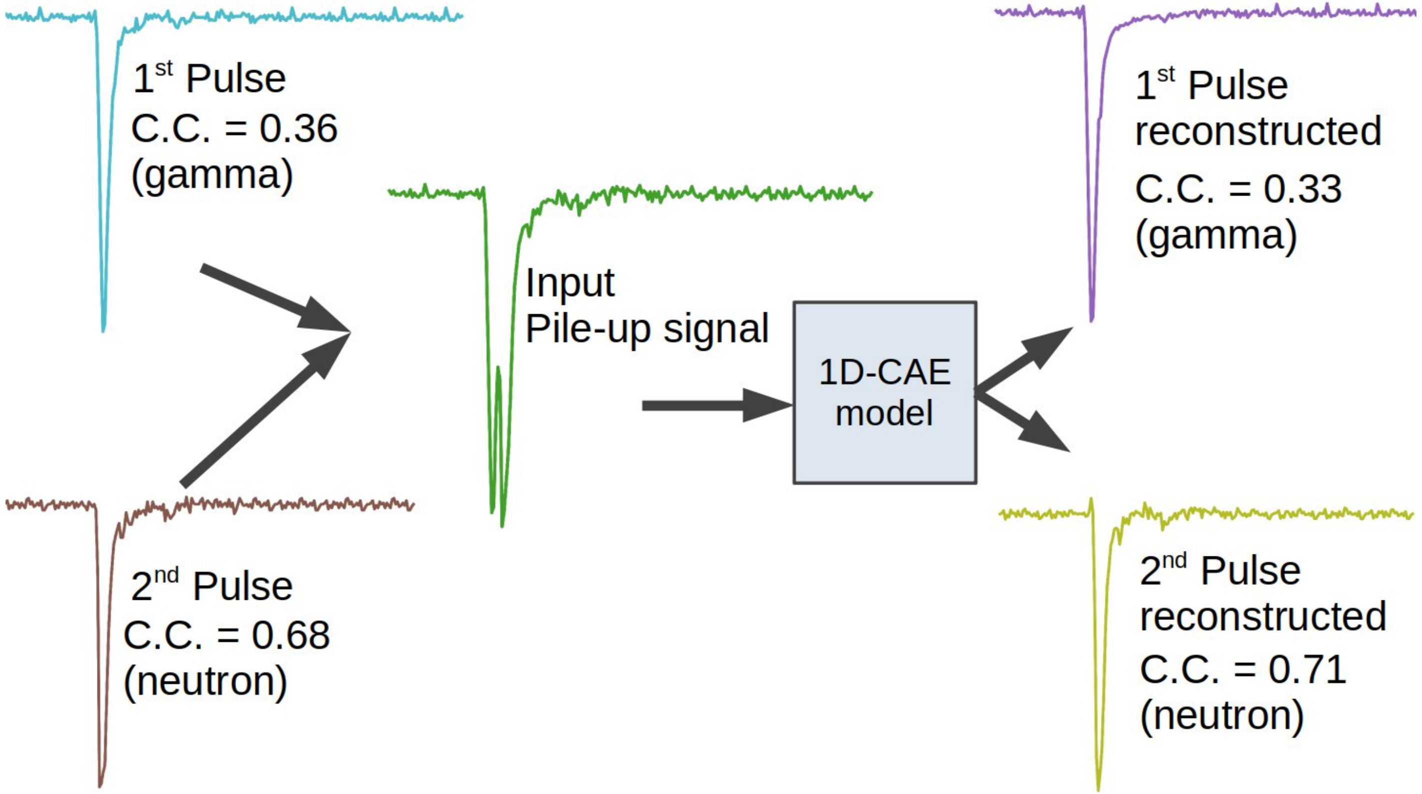
4. Data preparation

- Data acquisition from HIL (Heavy Ion Laboratory at the University of Warsaw) setup, providing neutrons and gammas.
- A database has been created with **“artificial” pile-up signals to train the model and have the ground truth for training.**
- Steps:
  - ➢ Take acquired signals directly from the digitiser. (without post-processing) **from 18 to 855 mV.**
  - ➢ Analysis based on C.C.
  - ➢ Take two events of different types: **gamma-neutron and neutron-gamma**
  - ➢ Shift one of the pulses between **12 and 160 ns** (3 and 40 samples)
  - ➢ Add both signals
- Two diferent dataset of : **10,000 events for each distance** between pulses and for each combination. In total **two datasets (training and test) of 380,000 for g-n and 380,000 for n-g.**
- No “uncertainty zone” events have been trained.
- 10,000 training EPOCHS.



Distribution of gamma and neutrons taking into account the result of C.C.
Intermediate zone remains untrained since it cannot be determined if it is neutron or gamma only with C.C.

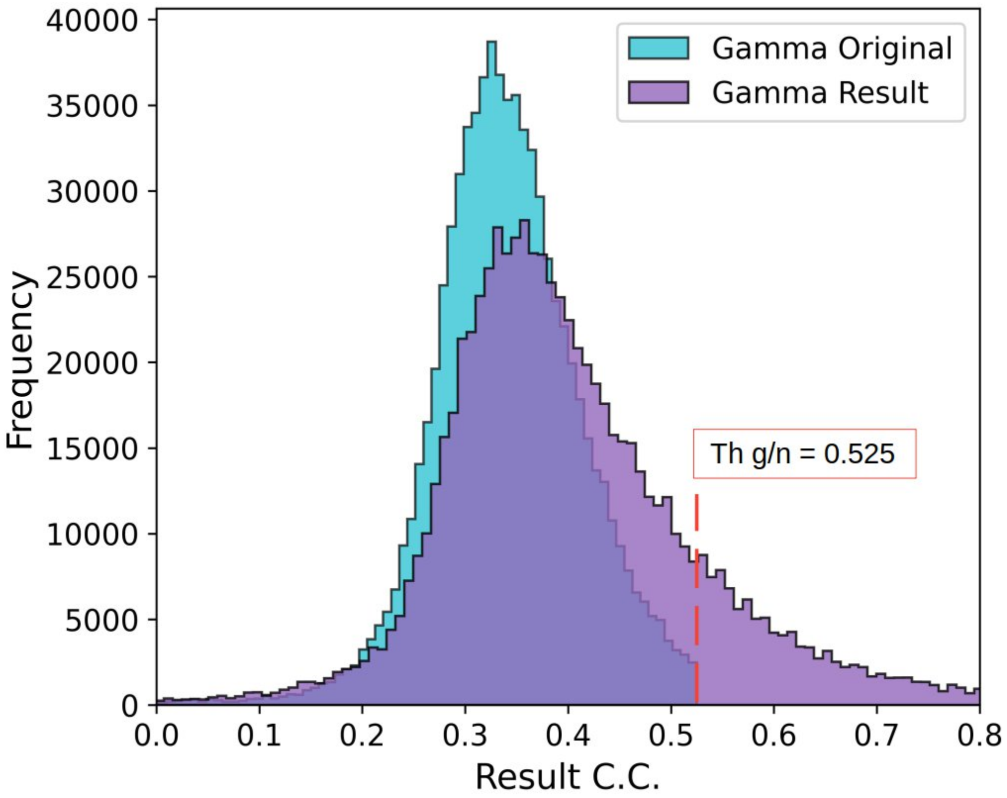
5. Analysis of reconstructed signals



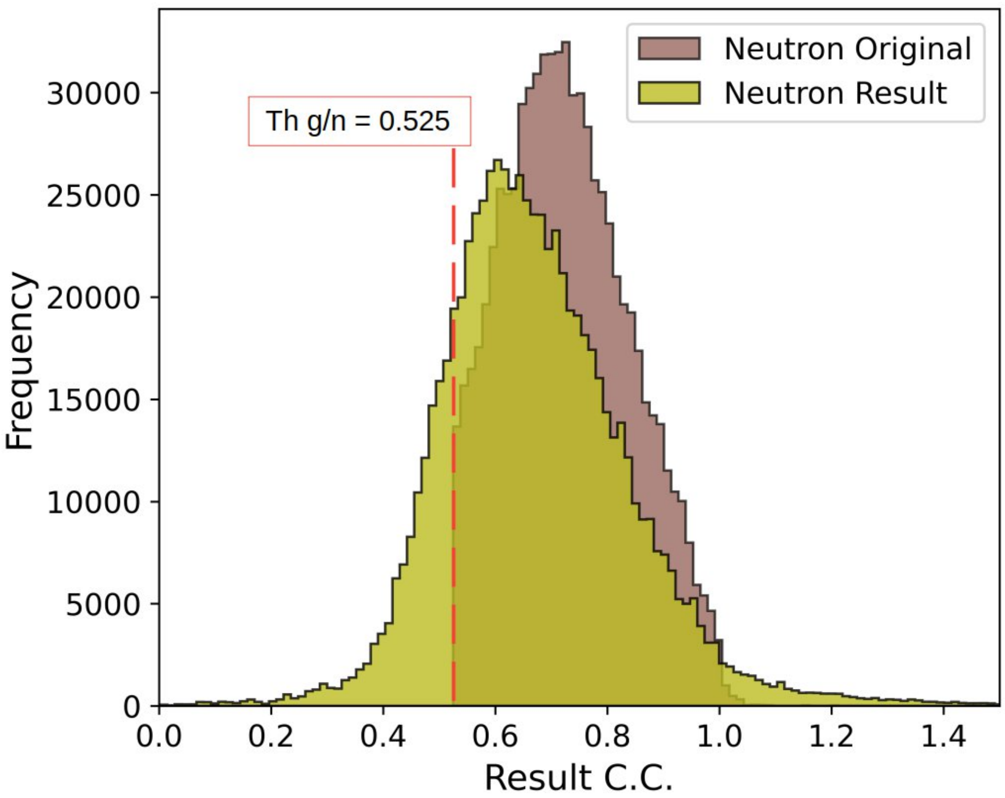
Example of using 1D-CAE trained model for the reconstruction of pile-up signals

- 70 ms for the reconstruction of each event, acceptable time to include the model in the offline analysis

6. Analysis of reconstructed signals



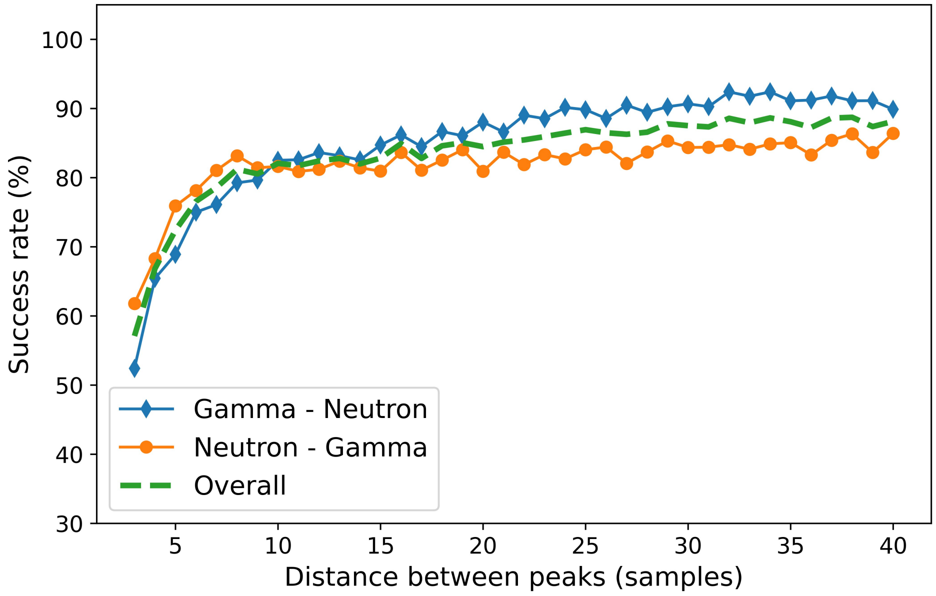
84.7% success in gamma-ray reconstruction

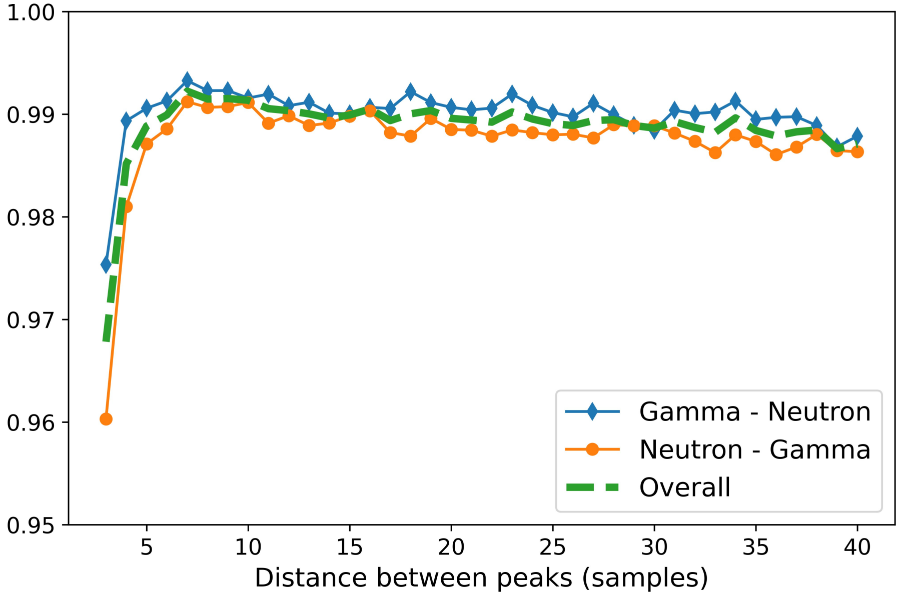


83.3% success in neutron reconstruction

6. Analysis of reconstructed signals

- The success rate and correlation were studied taking into account both combinations and the distance between pulses.





Average identification success = 83.53%

Average correlation between original signal and reconstructed signal **of 0.988**

7. Conclusions

- The 1D-CAE was tested with real detector signals, achieving a total **success rate greater than 80%**, after performing the C.C.

- It can be **integrated** into the offline analysis chain.

- Events that were previously discarded **now can be analysed**.

- In the future, integration of the model **into electronics for next generation of digitizers for NEDA.**

Thanks for your attention

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